The effect of ball-handling on lower extremity mechanics in soccer

Undergraduate Research Thesis
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Abstract

Nearly 240,000 soccer injuries are estimated to have occurred in the United States in 2014 with a high number of them non-contact in nature and involving the lower extremities. These injuries result in time-loss from training or match play, potential psychological consequences, and financial burdens. Epidemiological research suggests that these non-contact injuries may occur more frequently while ball-handling compared to defending in soccer. However, no prior studies have investigated the biomechanical implications of controlling a soccer ball with the feet while running and cutting that may help explain this finding. The purpose of this study was to compare knee and ankle joint moments and angles implicated in non-contact soccer injury mechanisms demonstrated during run-to-cut maneuvers performed with and without dribbling a soccer ball. Our hypothesis was that the cutting maneuvers performed while dribbling a ball would have a detrimental effect on biomechanical parameters associated with non-contact ankle and knee injuries. Seventeen healthy male collegiate soccer players participated in the study. Subjects performed ball-handling and running maneuvers while running straight ahead and also at a 45° cutting angle. All data were collected using three-dimensional motion capture with force plates embedded in the floor. Ball-handling had a significant effect on peak ankle internal rotation angle ($p=0.010$) and knee abduction angle ($p=0.024$). Changes in other parameters of interest, including peak ankle inversion moment and peak knee abduction moment, did not reach significance ($p>0.05$). In conclusion, ball-handling in soccer can detrimentally alter lower extremity joint mechanics of dynamic movements. The results of this study support the need for coaches to consider the implications of an athlete's sport-specific movements when creating training programs for teams and individuals.

Acknowledgements

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Introduction

Soccer is the most popular sport in the world with approximately 265 million participants in 2006, and it continues to gain broader participation.[1] Inherent with widespread participation is a multitude of soccer-related injuries that hinder performance with time-loss from training or match play, elicit psychological distress, and result in high costs for players and the healthcare system.[2,3] Acute soccer injuries are a significant cause for concern and information about these injuries is required to develop injury prevention programs to mitigate these consequences. Of the number of soccer injuries, most occur in the lower extremities,[4,5] and a high number of them result from non-contact mechanisms of cutting or landing with sudden change of direction or pivot.[6-8] From the 2014 High School Reporting Information Online (RIO) injury surveillance database, the ankle (47%) and knee (25%) were the most common locations of injury when analyzing ball-handling injuries to the lower extremities (thigh and lower).[9] Ligament damage occurred in 62% of the lower extremity injuries (sprains, incomplete and complete tears), which is often observed in injuries involving cutting maneuvers.[10]

Injuries that occur in soccer participants are diverse in cause and location, likely due to the wide range of required movements, increasing potential instances of tissue damage. Junge et al. has reported the incidence of soccer injuries as substantially higher in games than training sessions,[11] which may imply the increased intensity and vigor of a real game increases the likelihood of injury. It has been estimated that every elite male soccer player incurs approximately one performance-limiting injury each year,[12,13] suggesting the need for continuous prevention programs to decrease injury occurrence. Preventative programs focusing on musculoskeletal injuries, including ankle sprains and severe knee injuries, were evaluated and shown to be overall effective in their purpose.[14-18] From these data, the utility of prevention programs it is apparent. In taking steps towards an injury prevention strategy, the etiology and mechanisms of particular injuries should be explored to expand the identification and recognition of certain debilitating injuries.

Sprains, contusions, and strains of the lower extremities are among the most common injuries in male soccer players.[19] Muscle strains have been reported as the most prevalent, with 92% of these strains occurring in the lower extremities involving the hamstrings, hip adductors, quadriceps, and calf muscles, and accounting for almost one third of all time-loss injuries in professional soccer.[20] Though muscle strains are common, they are often less severe than acute ligament sprains, thus resulting in less time-loss from play. Of long-term sequelae resulting from ligamentous injury, recurrence often results in a longer period of absence than initial injuries.[21] With recurring injuries having a compounded effect, focusing on prevention of initial injury may mitigate consequences in the future. Being able to attenuate the severity of an initial injury in an active player may contribute to avoidance of a secondary injury.

Injuries, in general, leave players with a financial burden from proper treatment as well as time-loss from play and potential psychological distress from being injured. The average cost for medical treatment per soccer injury was estimated to be $150 in 2000, but costs can vary substantially depending on injury severity and/or proper rehabilitation.[12] Though definition of an injury is often dependent on reporters of the data, time-loss from training or work is invariably a cause for concern and can contribute to indirect costs of injuries as a result from lost productivity or ability for work. Lost sporting time was recognized to be dependent upon availability and quality of medical resources, most likely confounded by sociocultural background and level of play. Good rehabilitation may result in more time-loss to fully heal and return to play more safely, while incomplete or lack of rehabilitation after injury may result in faster return to play but an inherently higher risk for re-injury. In all injury implications, psychological distress of injury and rehabilitation should be acknowledged. Smith[2] reviewed the psychological and emotional impacts of rehabilitation from sports injury, finding self-esteem and mood disturbance as responses that can change as a result of the inability to cope with injury. Feeling controlled by an injury can leave a player ill-adjusted and can affect daily living. Severity of injury influences the extent of psychological stress, but its impact is evident nonetheless.

Cutting maneuvers are essential for successful performance in many sports and can also involve ball-handling, especially in soccer. Previously, sport-specific factors have been identified to alter biomechanical parameters during movements. Sport-dependent variations of upper-body positioning during run-to-cut maneuvers are presented as risk factors for non-contact anterior cruciate ligament injuries.[23] Receiving a pass as well as dribbling a ball in basketball has been reported to influence lower extremity mechanics related to ACL injury.[24,25] Previous research suggests that non-contact injuries may occur more frequently during offensive maneuvers compared to defending in soccer;[9] however, no studies have directly investigated how dribbling a soccer ball may alter lower extremity biomechanics. Understanding biomechanical alterations due to ball-handling during cutting maneuvers will enable preventative measures to be customized to the risks posed to athletes of different sports and positions.

The ball-handling movement in soccer is fundamental in soccer. Running with control of a ball with the foot is a learned task through training. Possibly due to the rudimentary nature of ball-handling to the sport, its effect on biomechanics implicating injury has not been considered in previous research. Tasks requiring a ball in soccer participation can include passing, receiving, shooting, and heading as well as ball-handling. With these tasks, it is often necessary to exaggerate movement to successfully accomplish the intention. For example, receiving a pass not ideally passed to a player’s feet during a run may lead him/her to strenuously lunge forward to maintain control of the ball. Other times, interference with a defender may alter the movement of an offensive player. Though all mentioned tasks have importance to investigate their effects on player biomechanics, ball-handling was explored as an offensive movement in which players focus and spend the most time on performing.

The thigh, knee, and ankle are the most commonly injured areas in soccer.[4] Of thigh injuries, injuries that can result are strains or contusions. In the knee joint, multiple types of acute injuries can arise (e.g., sprains, lesions, and dislocations). When compared to the thigh and knee, the ankle joint is unique in that a large majority (85%) of ankle injuries are sprains.[26] Of these sprains, a high proportion involves damage of lateral structures. The lateral ligament complex of the ankle includes three ligaments: the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL). Typically, mechanism of injury involves plantar flexion, inversion, and internal rotation during ground contact. Side-cutting maneuvers in sports, and specifically in soccer, can elicit a lateral ankle sprain from poor execution. From an anatomical perspective lateral ankle sprains are likely to occur because of the relative shortness of the medial malleolus allowing unobstructed inversion, and the tendency of the foot to invert, inversion sprains of this complex are common. In the lateral complex, the ATFL is the most commonly injured ligament due to its relative weakness and involvement in inversion stabilization.[27] Its damage is often the first injury in lateral ankle sprains.

In the knee joint, the anterior cruciate ligament (ACL) is one of the most commonly disrupted knee structures.[28] Its impairment results in lengthy disability time, high cost for treatment, and increases risk for longstanding consequences such as degenerative joint disease.[29,30] Non-contact ACL injuries have accounted for nearly three-quarters of all ACL injuries,[8] offering an opportunity for intervention of prophylactic programs designed to diminish the incidence of injury. Biomechanical parameters implicated in loading the ACL and contributing to injury involve knee abduction, often referred to as knee valgus, and internal tibial rotation while the knee is semi-flexed or near/past extension.[10,31,32] Concurrent injury to proximate knee structures during acute ACL injury is not unusual. In general, less knee flexion during the stance-phase results in a more vulnerable position for ACL injury, especially in addition to internal tibial torque applied to an ACL loaded by anterior tibial force or with insufficient hamstrings co-contraction.

This mechanism is probable in frequent cutting sports, such as soccer. Extensive research has continued to investigate ACL injury to identify risk factors; this study aimed to identify a mechanical basis for the observed trend of offensive lower extremity injuries, inherently including ACL injuries. The purpose of this study was to determine the effect of dribbling a soccer ball during a side-cut maneuver on knee and ankle joint moments and angles implicated in non-contact soccer injury mechanisms (ACL, lateral ankle injury). We hypothesized that ball-handling cutting maneuvers would have a detrimental effect on the biomechanical parameters previously associated with non-contact knee and ankle injuries.

Methods

Participants

A sample size of 17 subjects provided 80% power to detect an effect equal to anticipation during a side-cut maneuver[33] at $\alpha=0.05$ while accounting for the variability estimated from pilot data. Participants had no past history of traumatic knee or ankle injury (i.e., resulting in surgery and time loss) nor minor recent injuries (i.e., hindering but not resulting in time loss) in the past 3 months that limited their participation in soccer. Participants were required to be above a score of 7 on the Tegner Activity Scale[34] as well as a score of 12 or higher on the Marx Activity Scale.[35] They were either current members of a collegiate club team or had been members in the past 2 months and were able to perform jogging, jumping, pivoting, and cutting maneuvers without pain. All subjects provided IRB-approved informed consent prior to participating in the study.

Subjects for this study were accrued from the Ohio State Men's Club Soccer team, although recruitment welcomed potential participants fitting the inclusion criteria. Flyers posted in recreation centers as well as individual interaction were primary means of recruitment. After initial interest was gauged, every potential subject was directed to complete an online survey to determine eligibility in the study. If eligibility was confirmed, subjects were then contacted and a time was arranged to participate in the study at the OSU Sports Biomechanics Lab.

Experienced and skilled soccer players were recruited for this study in order to observe the effect of ball-handling in a more trained group of players. Inexperience and lack of ball control were thought to impinge upon the ability to complete the protocol effectively. A desire for ball-handling and non-ball-handling trials to follow identical trajectories when performed to maximize parallelism between conditions was a desired requirement for participants. This was done so potential deviations would be attributable to the addition of the ball instead of the two conditions being different movements.

Experimental setup

The non-dominant dribbling leg (i.e., the plant leg in a side cut maneuver) was tested during two conditions: non-ball-handling (NB) and ball-handling (BH). Leg dominance was determined as the leg the subject would use to dribble and kick the ball as far as possible. Subjects performed the NB and BH maneuvers while running forward (0°) and while cutting to 45°. Thus, each subject was recorded performing four different movements. A total of 32 trials, eight for each condition, were completed. Subjects first performed practice BH trials to obtain a controlled dribbling speed for each direction of maneuvering. In the NB trials, subjects' approach speed for each particular direction was kept within ±10 % of the mean speed determined from the practice BH trials for each respective direction. Approach speed was calculated using timing gates (Smartspeed PT, Fusion Sport; Australia) placed along the subject's path (Figure 1). All BH trials were conducted first, followed by the analogous NB trials. The order of cutting directions was randomly assigned. This order was maintained for both NB and BH conditions for a given subject.

The protocol for the study required subjects to control the ball only with their dominant leg during ball-handling maneuvers due to: (1) previous data collections that highlighted the presence of limb asymmetries in an active population during cutting maneuvers similar to this study, and (2) subjects were more comfortable dribbling with their dominant leg, diminishing foreseeable mishandling that could potentially exceed their capability to perform tasks repeatedly with their non-dominant leg.

Subjects were asked to wear indoor soccer shoes or shoes appropriate for playing soccer on a flat surface. Before each maneuver, subjects were informed which direction they would be performing the task. In all trials, subjects were given approximately 6 meters to run or dribble towards force plates embedded in the floor (Figure 1). In all 45° trials, a cone immediately beyond the force plates was placed to give a reference point towards which they were to dribble. In all BH trials, subjects were instructed to control the ball with only their dominant leg and to only use the anterior and lateral surface of this foot to approach the force plates and execute the side cut. Dribbling using the anterior and lateral surfaces of the foot is typical in a game environment, especially before an evasive maneuver is to be executed. In the BH-0° condition, subjects ran straight ahead while maintaining the dribbling technique with the ball. In the BH-45° side cut trials, subjects were instructed to plant their non-dominant leg (not in contact with the ball) and push off to continue in the 45° direction, maintaining control of the ball throughout. Successful trials were those that had proper approach speeds, clean force plate contact with the non-dominant (planting) foot, and when subjects were able to produce the desired maneuver with proper ball control.

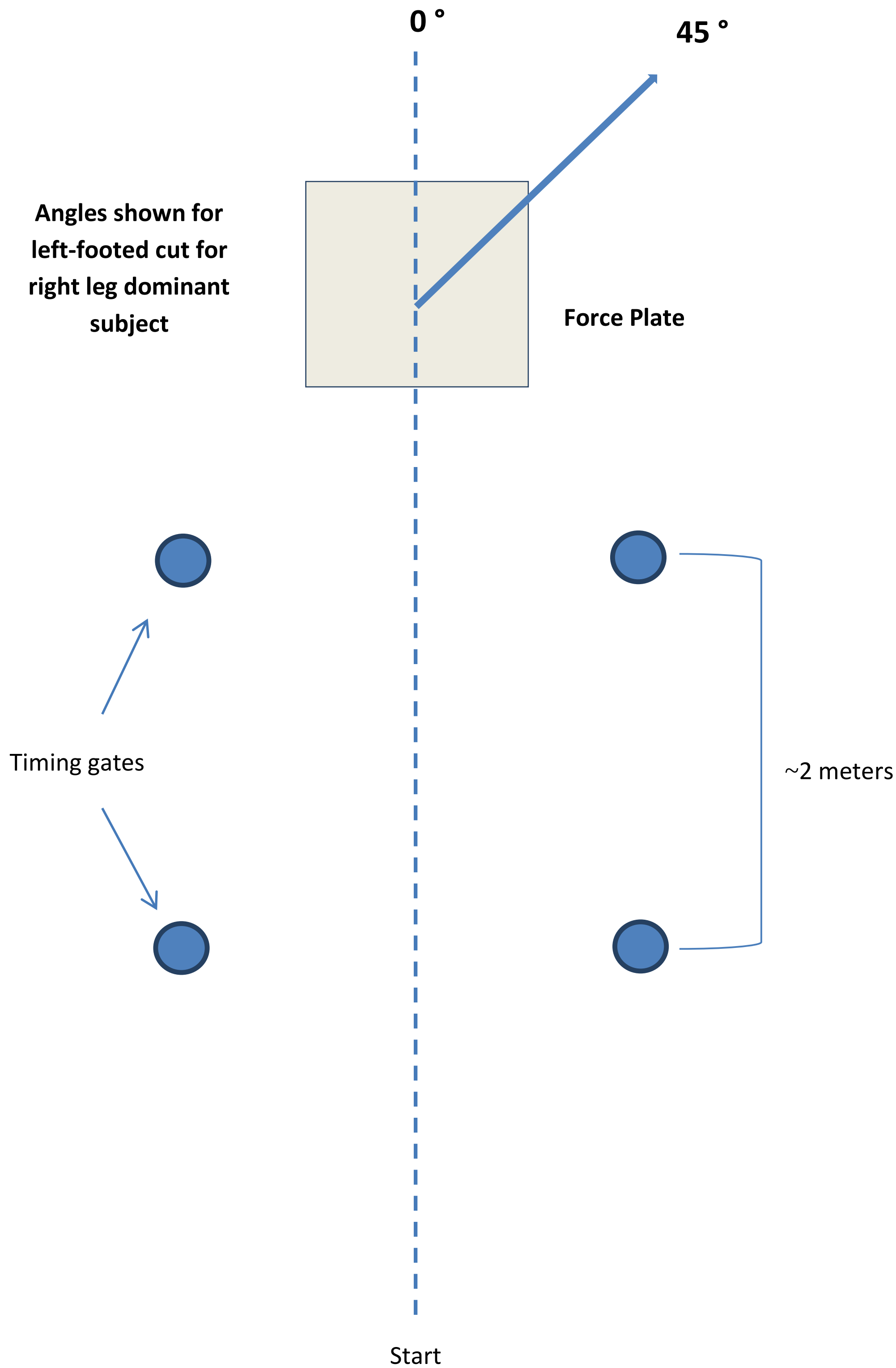

Figure 1. Experimental setup. Subjects began their trial by running through timing gates and performing the specified task upon crossing the force plate with indicative tape clearly labeling the directions.

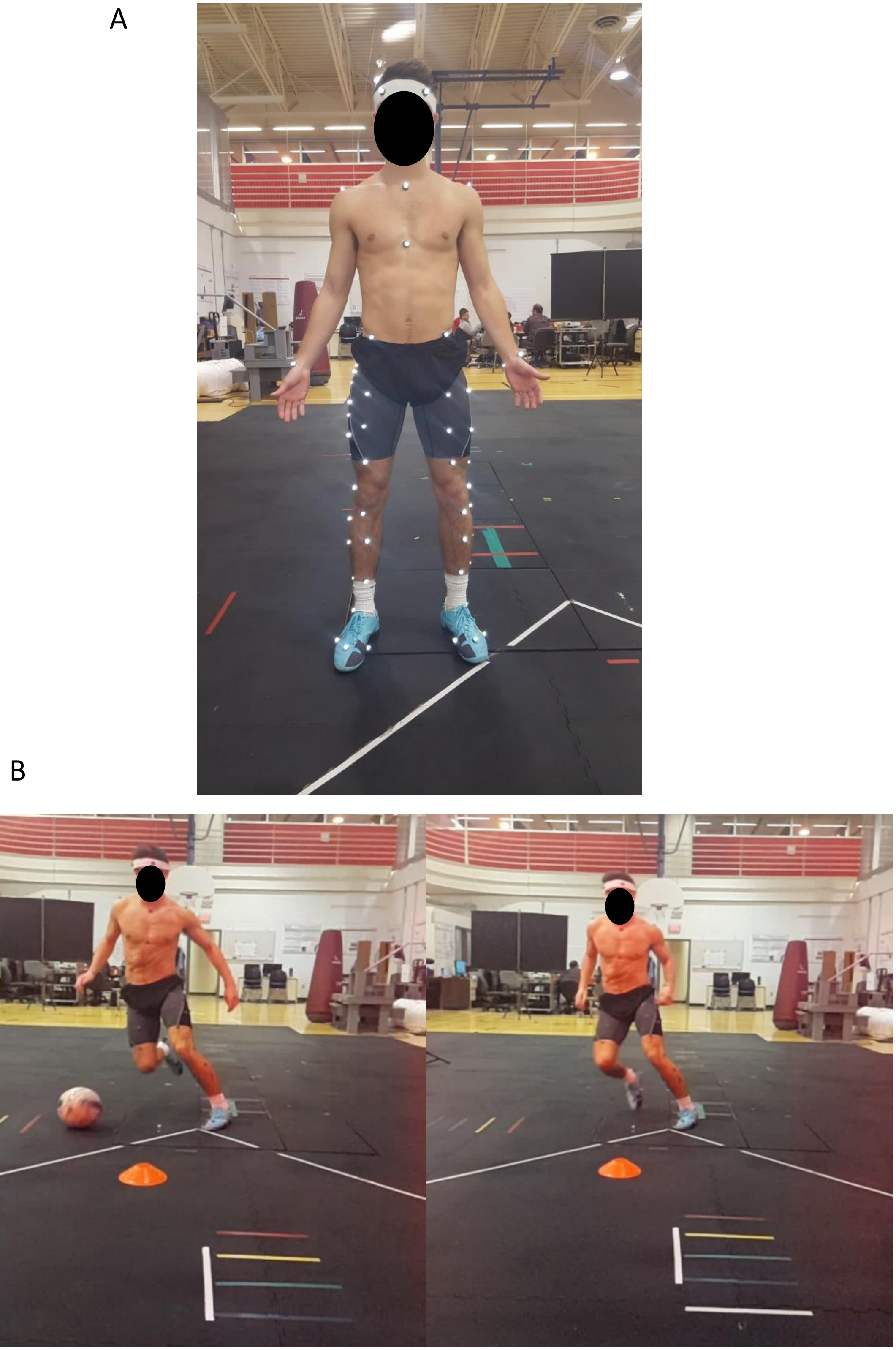

Figure 2. (A) Anterior view of marker set placement. (B) Cutting maneuvers at 45° demonstrated during BH (left) and NB (right).

Our original protocol for data collection included two additional cut angles: 90° and 135°. The rationale was that soccer players often perform a plethora of different cutting maneuvers in a game at many different angles. We initially theorized that analyzing the forward run at 0° in addition to side cutting at 45°, 90°, and 135° would represent a more complete synopsis of game-like movements in soccer players. However, after implementing 90° and 135° side cutting in pilot subjects, the precision and repeatability of these more dynamic tasks were deemed too highly inconsistent for each subject and were not reported. The task, although game-like, was too difficult for subjects to repeat consistently. Therefore, we decided to focus strictly on the forward run and 45° side cut due to the ability for subjects to be able to perform these tasks consistently for data collection purposes.

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Data Collection and Analysis

Retroreflective markers were placed on subjects using the marker set placement previously used by Jamison et al.[36] for the upper and lower body (see Figure 2). Lower body markers were arranged in a point cluster method on the skin to reduce the error of kinematic measurement due to non-rigid body movement and better simulate a rigid body segment, demonstrated by Andriacchi et al.[37] Marker data were collected at 300 Hz using an optical motion capture system (MX-F40, Vicon Motion Systems, Oxford, UK) and filtered using a 4th order lowpass Butterworth filter at 6 Hz. Ground reaction forces were sampled at 1500 Hz from six force plates (Bertec Corp., Columbus, OH, USA).

Before the recording of experimental trials but after the placement of markers on the subject, calibration, full-body range-of-motion, knee flexion, and hip joint range-of-motion trials were recorded in order to create a digital model specific to each subject. The individual digital model system allowed hip joint centers and knee joint centers to be readily calculated for trial-labeling purposes in the data analysis process. Before experimental trials, medial knee and ankle markers were removed in addition to the inferior lateral knee marker. These markers were solely used to calculate knee joint center in aforementioned preliminary trials, and their inclusion in dynamic trials was not necessary for post hoc analysis.

During data collection, one or more personnel controlled computer functions of recording trials while another was responsible for instructing the subject on each maneuver to be performed. The field experimenter also determined trials sufficient for analysis based on quality of foot-strike upon the force plates, implemented dribbling technique, and cutting angle. Sufficient foot-strike included the entire foot remaining on one or more force plates throughout the stance phase. Ball-handling trials required more subject practice and trials to record sufficient data due to increased difficulty of the tasks. Once subjects were comfortable in performing the intended task correctly, eight trials for each condition (BH-0°, BH-45°, NB-0°, NB-45°) were recorded to ensure at least three quality trials would be viable for analysis. NB trials tended to be more consistent and easier for subjects to perform repeatedly, as expected.

After data collection of a subject, study personnel were able to begin data analysis, initially by reconstructing digital marker data in Vicon computer software for every trial recorded. This included labeling over the entirety of the trimmed recorded trial as well as filling gaps in certain markers over time. Marker gaps which were smaller than 30 frames were filled using software operations. Other Vicon operations were run to gather relevant data for analysis, such as heel-strike and toe-off events and labeling proper force plate(s) of foot strikes. Within each subject, the non-dribbling foot was of relevance in determining gait events; the ball-handling foot's interaction with force plates was not of interest for analysis, as it was not in the aim of the study. Trials deemed viable for analysis underwent a series of dynamic operations in the software to calculate and display kinetic and kinematic data over the trial's length for each joint in three dimensions. Reviewing the progressed trials and finding no apparent cause for concern, trials were available for data pulling for analysis.

Vicon BodyBuilder and MATLAB scripts were used to calculate kinematics and kinetics of the lower extremities for each trial. Distinct parameters were chosen for planned statistical comparison based on previous biomechanical parameters linked to lateral ankle sprain and ACL injury. These included the peak stance-phase angles from each trial for the following parameters: ankle inversion, ankle internal rotation, knee abduction, and tibial internal rotation. Peak stance-phase external moments were calculated for these parameters as well. Means for sagittal and frontal plane knee angles as well as ankle internal rotation angle were calculated over the entire stance-phase. Joint moments were normalized by percent body weight and height.

Statistics

Three representative trials from each of the four conditions were selected for analysis, and the defined parameters from the three trials were averaged for each condition. Linear mixed models for repeated measures with subjects as random effects and ball-handling, cutting angle, and ball-handling-cutting angle interaction as the fixed effects were used to estimate the changes in the various kinematic and kinetic parameters between conditions (SAS Version 9.4; SAS Institute Inc.; Cary, NC). Least squares means and corresponding contrasts of the fixed parameters from the mixed model were used to estimate the differences between conditions. The significance level was set *a priori* $\alpha \leq 0.05$.

Results

Seventeen healthy male collegiate club soccer players volunteered to participate in this study (Table 1). The primary effect of ball-handling as well as the effects of cut angle and the interaction between these two variables are reported in Table 2. For all results presented, 64 of the 68 recorded conditions (four conditions per subject) were used in statistical analyses due to four conditions automatically considered outliers based on the Grubb's statistical test for outliers (Minitab Inc.). Significant differences between NB and BH conditions were found for peak ankle internal rotation angle (p= 0.010) and peak knee abduction angle (p = 0.024). Subjects displayed greater peak knee abduction angle during BH maneuvers and greater peak ankle internal rotation during NB maneuvers. Other kinematic parameters linked to ankle injuries (i.e., ankle inversion angle) and ACL injuries (i.e., tibial internal rotation angle) did

Table 1. Subject demographic data as well as division of soccer positions among subjects

Characteristic	Mean ± SD
Participants (n)	17
Age (years)	20.59 ± 1.91
Height (m)	1.77 ± 0.07
Body Mass (kg)	77.59 ± 8.29
Defender (*n*)	6
Midfielder (*n*)	8
Forward (*n*)	3

Table 2. Least squares means and standard deviations of peak ankle and knee angles for investigated parameters during stance phase BH and NB conditions. Units are in degrees. Positive values represent greater parameter angles. Significance is noted with an asterisk (p<0.05).

	Cut	0°	45°	BH effect [p (F)]	Cut Angle effect [p (F)]	BH*CutAng Interaction
Ankle Inversion	BH:	5.09 (4.28)	5.34 (4.5)	0.513 (0.45)	0.737 (0.11)	0.970 (<0.001)
	NB:	5.45 (4.68)	5.65 (4.48)			
Ankle Internal Rotation	BH:	0.54 (8.43)	-3.39 (8.55)	0.010 (8.86) *	<0.001 (29.63)*	0.330 (0.98)
	NB:	3.9 (8.24)	-1.79 (8.03)			
Knee Abduction	BH:	3.13 (5.01)	4.03 (5.1)	0.024 (6.17) *	<0.001 (24.00)*	0.002 (11.35)*
	NB:	-0.61 (5.12)	4.24 (4.94)			
Tibial Internal Rotation	BH:	15.89 (6.95)	16.6 (7.01)	0.543 (0.38)	0.004 (9.51)*	0.057 (3.87)*
	NB:	14.28 (6.76)	17.49 (6.64)			

not reach statistical significance (p> 0.05). The cut angle (0° versus 45°) had a significant impact on all measured parameters with the exception of ankle inversion angle. The effect of ball-handling was dependent upon the cut angle for knee abduction and tibial internal rotation, shown as the BH*CutAng interaction. Measured kinetic parameters are shown in Table 3. No parameters displayed significance in regard to the main effect of ball-handling (p>0.05). The effect of cut angle was significant for all parameters, and the interactive effect between ball-handling and cut angle was evident only for ankle inversion moment.

Table 3. Least squares means and standard deviations of peak ankle and knee moments for investigated parameters during stance phase BH and NB conditions. Moments presented as %BW*ht. Positive values represent greater parameter magnitudes. Significance is noted with an asterisk (p<0.05).

Parameter	Cut	0°	45°	BH effect [p (F)]	Cut Angle effect [p (F)]	BH*CutAng Interaction
Ankle Inversion	BH:	1.22 (1.00)	1.73 (1.00)	0.299 (1.16)	0.037 (4.71)*	0.060 (3.78)
	NB:	1.33 (1.00)	1.43 (0.92)			
Ankle Internal Rotation	BH:	0.71 (0.41)	0.20 (0.41)	0.370 (0.77)	<0.001 (68.28)*	0.758 (0.08)
	NB:	0.61 (0.41)	0.10 (0.41)			
Knee Abduction	BH:	1.83 (3.36)	6.52 (3.47)	0.074 (3.82)	<0.001 (97.42)*	0.352 (0.89)
	NB:	0.41 (3.67)	6.11 (3.47)			
Tibial Internal Rotation	BH:	1.22 (1.22)	2.45 (1.33)	0.619 (0.26)	<0.001 (20.96)*	0.090 (3.04)
	NB:	1.63 (1.43)	2.14 (1.33)			

Figure 3 presents the sagittal and frontal plane knee angles over the entire stance phase for 0° and 45° cut angles during BH and NB conditions. Knee flexion angle appeared to be very similar for BH and NB conditions as well as when comparing 0° and 45° cut angles. Ball-handling appears to result in a more pronounced effect on knee abduction angle during the 0° trials compared to 45° cutting. Knee abduction angle was elevated during ball-handling trials at 0° throughout the entire stance phase.

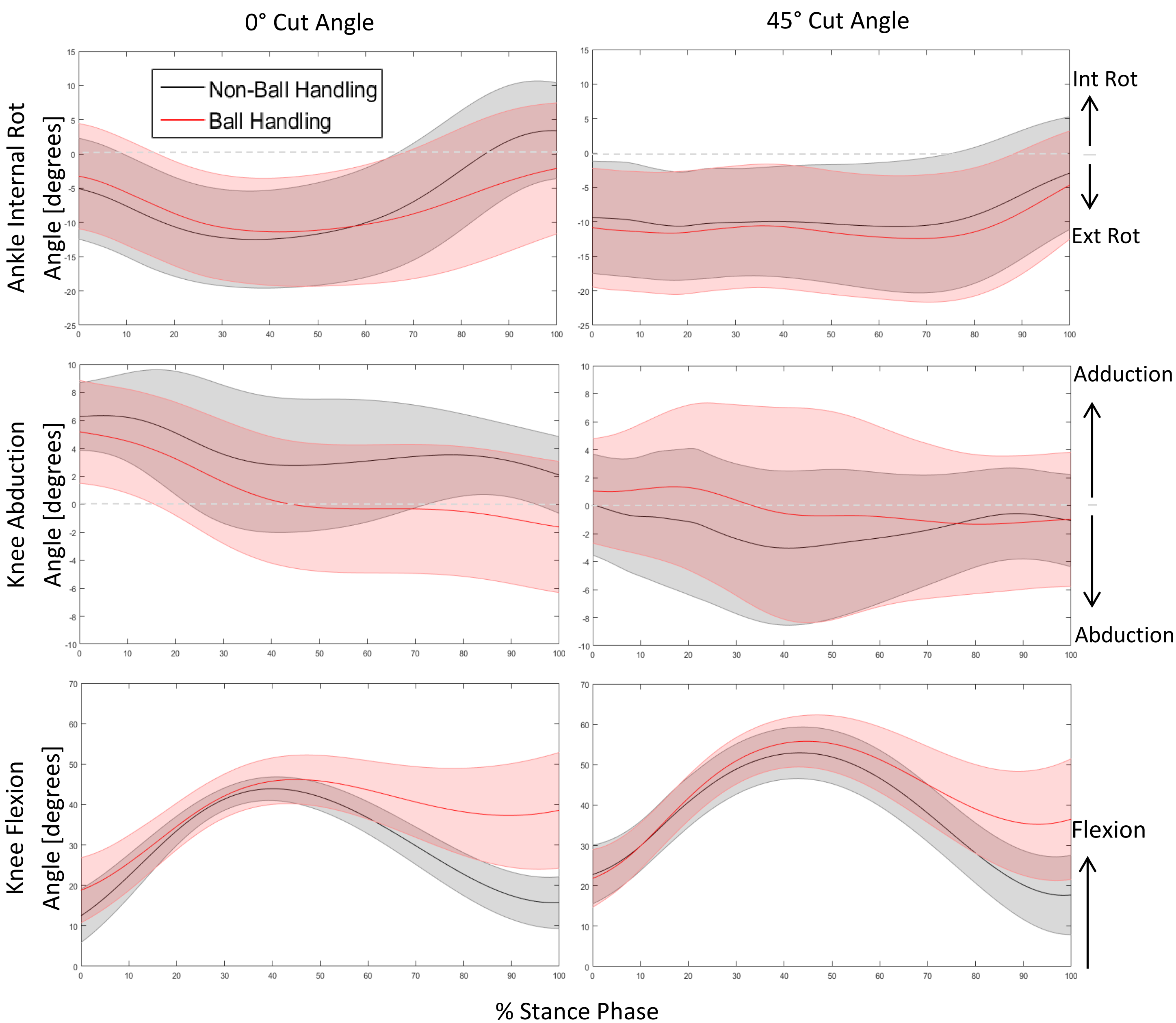

Figure 3. Mean (solid line) and standard deviations (shaded area) for ankle internal rotation angle, knee abduction angle, and knee flexion angle over the entire stance phase comparing BH and NB conditions at 0° and 45° cutting angles.

Discussion

To our knowledge, this study is one of the first to investigate biomechanical differences in side-step cutting during the soccer-specific task of dribbling. We hypothesized that introducing a ball to players during cutting maneuvers would distract the player and result in altered biomechanical parameters associated with ankle and/or knee joint injury mechanisms. Peak knee abduction angle was greater during ball-handling conditions, supporting our hypothesis and suggesting that players tend to alter their postural alignment when dribbling. Contrary to our hypothesis, subjects tended to internally rotate the foot of their plant leg less when dribbling. While these results do not include every type of movement performed with a ball in soccer, it may motivate future investigations by identifying differences that offensive ball-handling may present. Gaining a better understanding of the effect of ball-handling on lower extremity mechanics may help to guide the improvement of prophylactic programs, which have already proven effective in preventing injuries in soccer.[15,38]

Previous research indicates that simulating a game-like environment for sport-specific tasks increases the likelihood for altered lower extremity biomechanics implicated in knee ligament injury.[23-25,39] These studies generally focus on the lower extremity postural changes due to an external stimulus affecting the postural positioning of the upper body. In ball sports such as football, lacrosse, and basketball, the objectives of each sport require the involvement of the upper body, specifically the hands (e.g., throwing, passing, shooting, etc.). By contrast, in soccer the lower extremities are responsible for the sport-specific objectives (e.g., dribbling, passing, shooting, etc.). This fundamental difference of lower body demand dissimilar from upper body-dependent sports supports this study’s importance. This study aimed to identify the effect of ball-handling in soccer—a predominantly lower body sport— to obtain a better understanding of sport-specific factors that alter lower extremity mechanics.

The detrimental change in peak knee abduction angle due to ball-handling is consistent with an increased risk of knee injury while ball handling. Knee abduction angle has previously been linked in predicting knee abduction moment and contributing to loading the ACL.[10] This trend towards more knee abduction is indicative of a player changing postural alignment to effectively control the ball and maneuver towards a new direction. Since cutting maneuvers are generally recognized to pose athletes with a heightened risk of non-contact injuries,[7,36] we hypothesized that the 45° cutting maneuver would yield greater differences between ball-handling conditions and explain the trend towards offensive injuries observed by Monfort et al.[9] However, the 0° conditions showed a more appreciable difference than the 45° conditions in knee abduction angle over the stance phase (Figure 3)**.** This finding may suggest that the direction of player movement has an effect during ball-handling. Postural positioning changes while ball-handling could be more or less overt depending on the performed task. Ball-handling may more detrimentally alter straight-forward movements, otherwise considered to be relatively low-risk, compared to higher-risk movements such as 45° cutting.

Ankle internal rotation also displayed a more profound difference at 0°, but this difference was not consistent with our hypothesis. Ball-handling showed less internal rotation of the plant foot over the stance phase, signifying that ball-handling alone may not contribute to the mechanics often observed in ankle inversion injury. Though the trend towards offensive injuries was noted,[9] Brophy et al. conversely observed the majority of non-contact ACL injuries in soccer players occurred while defending.[7] However, it is noteworthy to examine the difference in data collection methods and sample characteristics between the two studies. The former study was reliant on online injury reports from athletic trainers; the latter study collected data from videos recorded at the time of injury and included thorough reviews to describe detailed and accurate accounts of the incidents. Furthermore, Monfort et al. investigated high school soccer players' injuries, while Brophy et al. primarily examined collegiate and professional players. Thus, Brophy et al. reported results that may have more relevance to the collegiate population of this study. Additionally, considering other offensive maneuvers such as kicking, receiving, and heading (with jumping) could provide more insight into explaining these observations.

The pre-planned nature of subject movement may help explain the finding that the majority of measured parameters failed to show appreciable difference with ball-handling. Subjects were aware of the maneuver to be performed before every trial, potentially allowing postural adjustments to be made well before the execution of the maneuver. Studies that have focused on cutting maneuvers have found a significant increase in lower extremity loading during unanticipated cutting tasks compared to identical anticipated tasks.[40] Assessing the effect of anticipation was outside the scope of this pilot study, so we implemented only anticipated movements. If feasible, studies implementing unanticipated cutting tasks while ball-handling would offer more game-representative information. Additionally, participants were experienced and skilled soccer players, and were considerably comfortable in dribbling and cutting with a ball. This could potentially explain the lack of differences observed between BH and NB conditions. Essentially, more skilled players with experience may be better at adapting to sport-specific maneuvers because they perform them regularly. Novice or strictly recreational soccer players, who account for the vast majority of the world's soccer population, could potentially elicit different results from undeveloped technique in dribbling.

Simply controlling a ball while running forward can alter lower body movement. This altered positioning of the lower body could conceivably result in a player more vulnerable to injury if tackled by an unexpected defender. This interpretation and the fundamental demand of a ball-handler to devote some level of attention to the ball at his/her feet may contribute to an ensuing injury from another player. Harpham et al. demonstrated that head impact severity in football players was strongly associated with visual perception quickness and that performing well with visual quickness requires a high level of attentional focus.[41] Ball-handling in soccer requires the attention of a player and can interfere with awareness of immediate defenders and accompanying impacts. Visual focus interference can be detrimental and its manifestation through ball-handling may pose a risk for injury.

Alongside visual interference, neurocognitive performance may confound the effect of ball-handling on lower extremity mechanics during ball-handling. It has been found that poorer neurocognitive function is correlated to an increased incidence of anterior cruciate ligament injury.[42] However, the underlying injury mechanisms that drive this relationship have yet to be elucidated. Additionally, previous research suggests that the addition of a distracting task during a movement, which is common during athletic competition, can influence lower extremity function.[43] Therefore, our future work will consider the relationship between joint mechanics, sport-specific distractions, and neurocognitive ability to more fully understand the risks posed to athletes.

This study assessed neurocognitive function subjects through the ImPACT® test. Because the focus of this study involved reporting the effect of ball-handling on joint mechanics, analysis of ImPACT® test results was excluded. The relationship between neurocognitive ability and ACL injury incidence has been evaluated; however, to support this finding, future investigations may be able to illuminate the subsequent relationship of neurocognitive ability to joint mechanics.

While this analysis of ball-handling in soccer offers novel insight into sport-specific movement, addressing the limitations of this study could assist future studies of similar nature. Having a more diverse sample would improve the reach and translatability of observed results in youth, high school, professional, etc. populations. Additionally, included subjects played on the same soccer team, describing only a small subset of trained players in college. Herrero et al. reported unequal distribution of injuries in soccer when stratified by player position, with more injuries occurring to midfielders and defenders compared to forwards.[44] The unequal distribution and relatively small subset sizes among positions prevented this comparison in our study. By accounting for player position and creating appropriate sample sizes to investigate position-specific differences in ball-handling movements, a more thorough understanding of each position's movement tendencies can be assessed.

We also acknowledge that previous research has shown a 3-8 times greater incidence rate of ACL injury in females compared to males[45-47] in addition to a higher incidence of ankle sprain in females.[48] Because this study only investigated males, there is motivation to expand this research to female soccer players and implement gender comparisons. Females have demonstrated greater magnitudes of parameters linked to ACL injury when compared to males.[49,50] Comparison of ball-handling mechanics in females would expand knowledge on these discrepancies. Additionally, future research addressing the shoe-surface interaction on mechanics would grant further understanding of the factors involved in non-contact ball-handling injuries. Considering cleats versus indoor shoes, and grass versus synthetic turf or gym floor, will improve the extensive list of factors that contribute to ACL and ankle injuries in soccer players. In spite of these limitations, this study has demonstrated the potential utility of investigating how sport-specific factors influence lower extremity mechanics.

Conclusion

This study is the first to investigate the biomechanics inherent in soccer ball-handling in an attempt to explain previous observations of offensive injury rates in soccer. Ball-handling in soccer can detrimentally alter lower extremity joint mechanics of dynamic movements, although a high number of investigated parameters failed to show differences. The results of this study support the need for future studies to progress the understanding of the effect of ball-handling. In addition, our findings establish the need for coaches to consider the implications of an athlete's sport-specific movements when creating training programs for teams and individuals.

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